Effective Radiative Forcing of Contrail Cirrus (Towards Determining Contrail Cirrus Efficacy)

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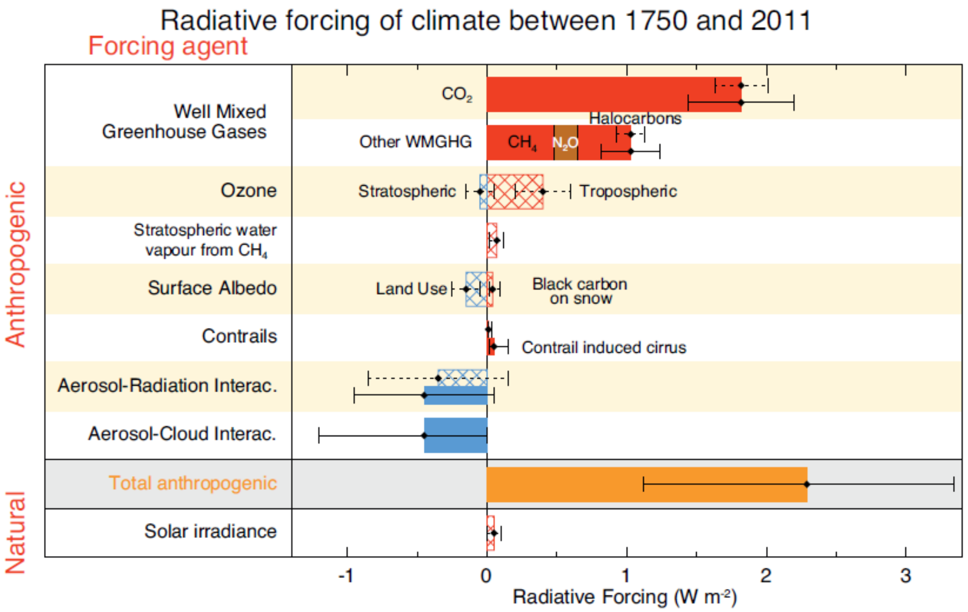
Quantifying the Importance of Various Climate Impact Components

Various emission components add up to total aviation climate impact

Are we using the best possible parameters for ranking their individual contributions and for assessing compensation effects?

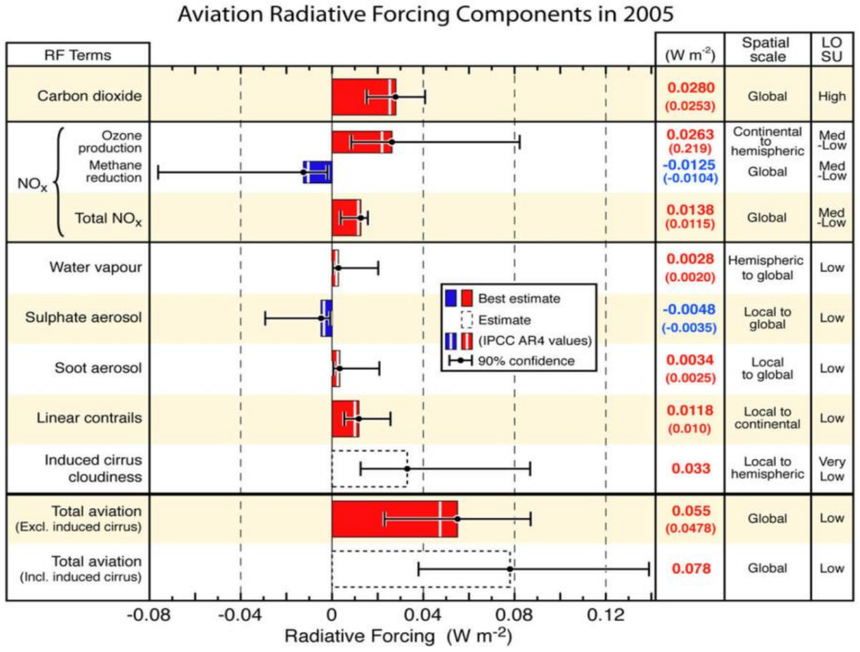
Aviation as Part of Anthropogenic Radiative Forcing/Climate Impact



IPCC AR5 (2013)

Numerous individual contributions (emission sectors and components) amount to total anthropogenic climate impact. One of them is contrail cirrus, which is exclusively contributed by the aviation sector.

Lee et al.(2009)



Estimating the radiative forcings of individual components has been the usual method to assess their relative importance for climate impact.

Contrail cirrus (including line-shaped contrails) make a large contribution to aviation radiative forcing.

Radiative Forcing, Efficacy and Climate Response

$$\Delta T_{sfc}^{(i)} = \lambda \cdot RF^{(i)}$$

Radiative forcing (*RF*) is a good metric for the expected global **surface temperature change (ΔT_{sfc})** under the assumption that there is a constant **climate sensitivity parameter (λ)**, independent of the forcing component (*i*).

If λ is forcing-dependent, it is required to know the forcing **efficacy (*r*)** to retain the possibility for assessing various forcings in terms of RF:

$$\Delta T_{sfc}^{(i)} = r^{(i)} \cdot \lambda^{(CO2)} \cdot RF^{(i)} \qquad r^{(i)} = \lambda^{(i)}/\lambda^{(CO2)}$$

Recent experience has suggested that using the **effective radiative forcing (*ERF*)** - instead of the conventionally defined RF - leads to a better comparability of various forcings without the need to determine dedicated efficacy parameters.

$$\Delta T_{sfc}^{(i)} = \lambda'^{(CO2)} \cdot ERF^{(i)} \qquad ERF^{(i)} \approx r^{(i)} \cdot RF^{(i)}$$

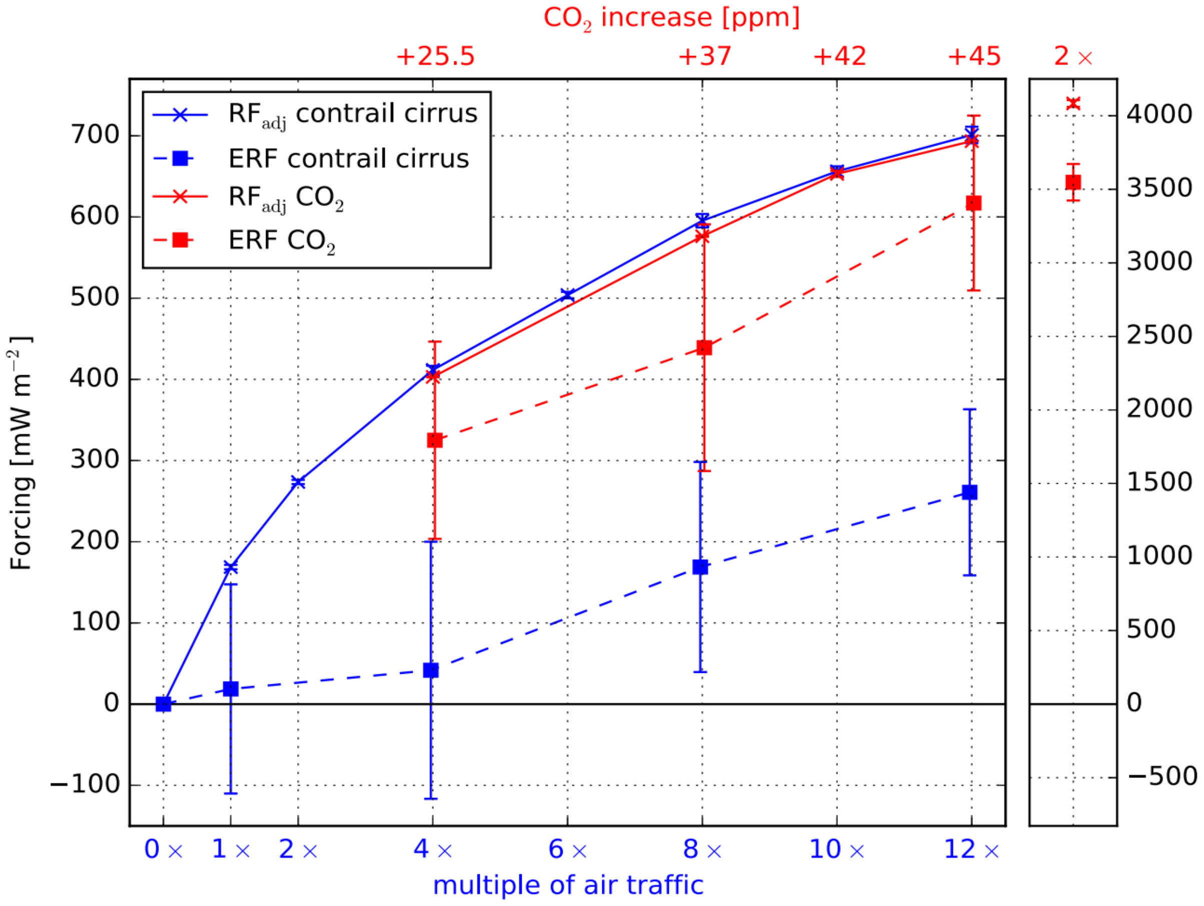
Efficacy and Effective Radiative Forcing of Contrail Cirrus

Evidence of an efficacy much lower than 1 has been provided for line-shaped contrails → (Ponater et al., 2005; Rap et al., 2010)

During the last 10 years an appropriate contrail cirrus parameterisation for global climate models has been developed and used for contrail cirrus *radiative forcing* calculations (Bock and Burkhardt, 2016, 2019).

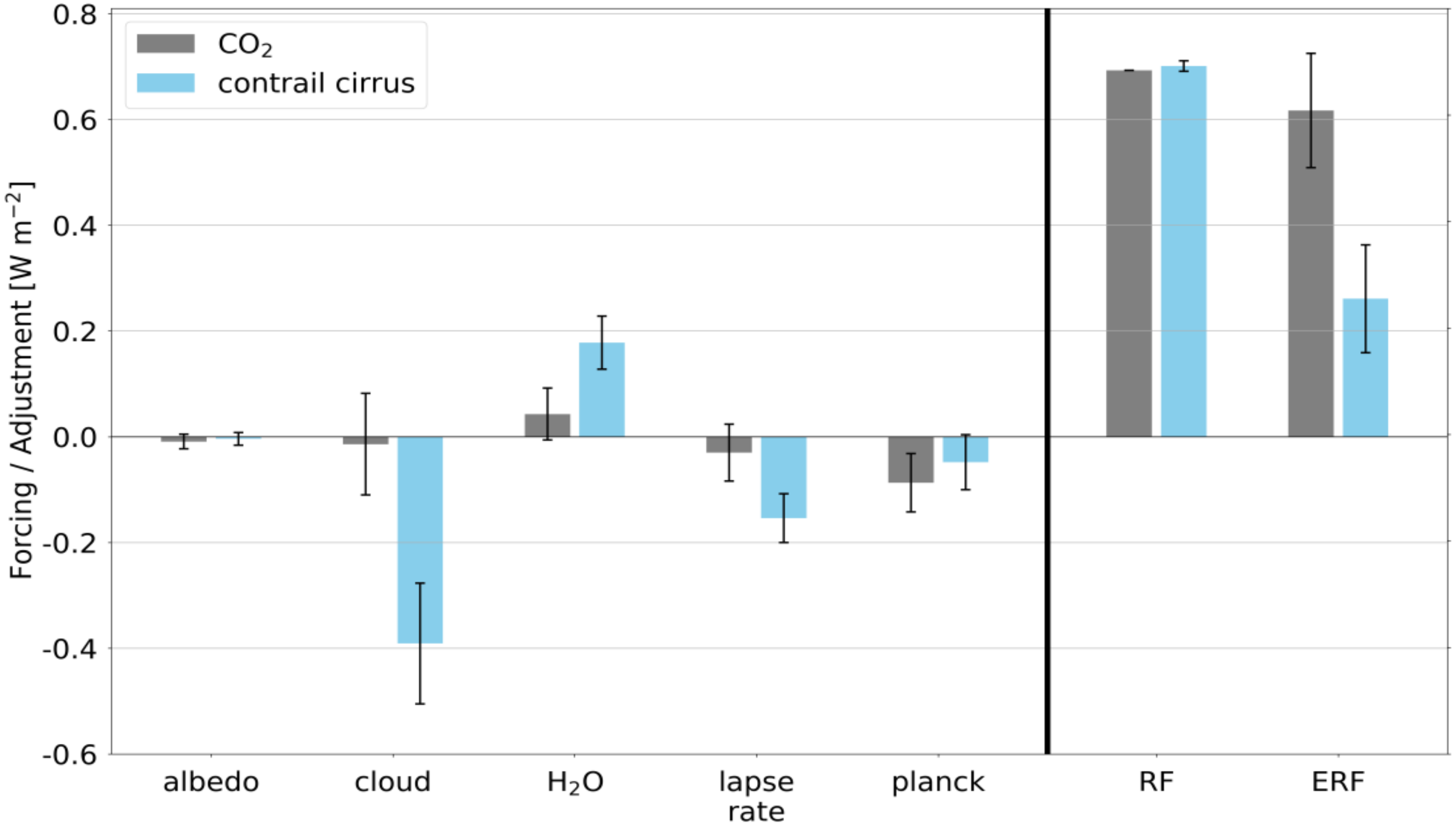
Bickel et al. (2020) used this framework for an attempt to quantify the *effective radiative forcing* for contrails cirrus. Another topic of their work was to identify potential differences concerning atmospheric feedbacks induced by CO_2 forcing and contrail cirrus forcing.

Effective Radiative Forcing of Contrail Cirrus



ERF is more strongly reduced with respect to conventional RF for contrail cirrus (~65%) than for CO_2 (<15%). ***(Bickel et al., 2020)***

Comparison with CO_2: Differences in Rapid Adjustments

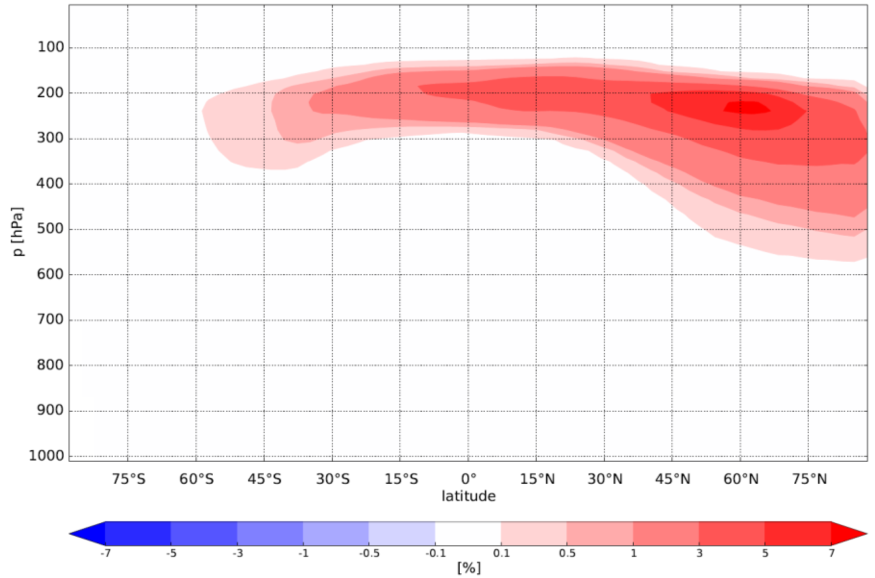


Contrail Cirrus ERF is reduced mainly by a significant adjustment of natural clouds, which partly compensates the contrails' direct radiative effect.

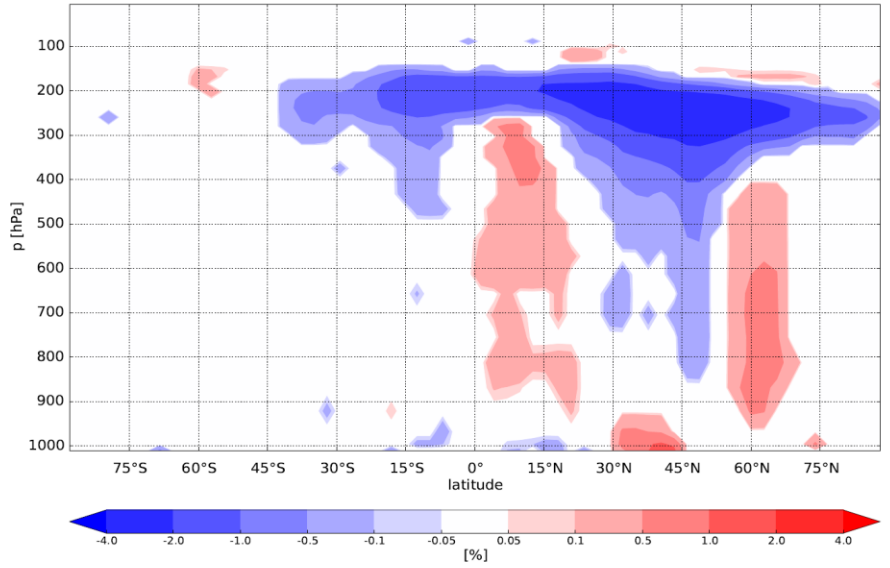
(*Bickel et al., 2020*)

Contrails Cirrus Development Impacts on Natural Cirrus

Contrail Cover Increase in ATR-12

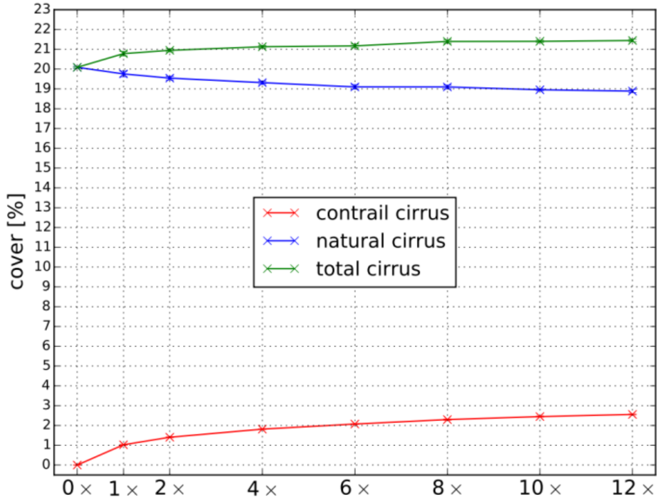


Natural cloud cover change in ATR-12



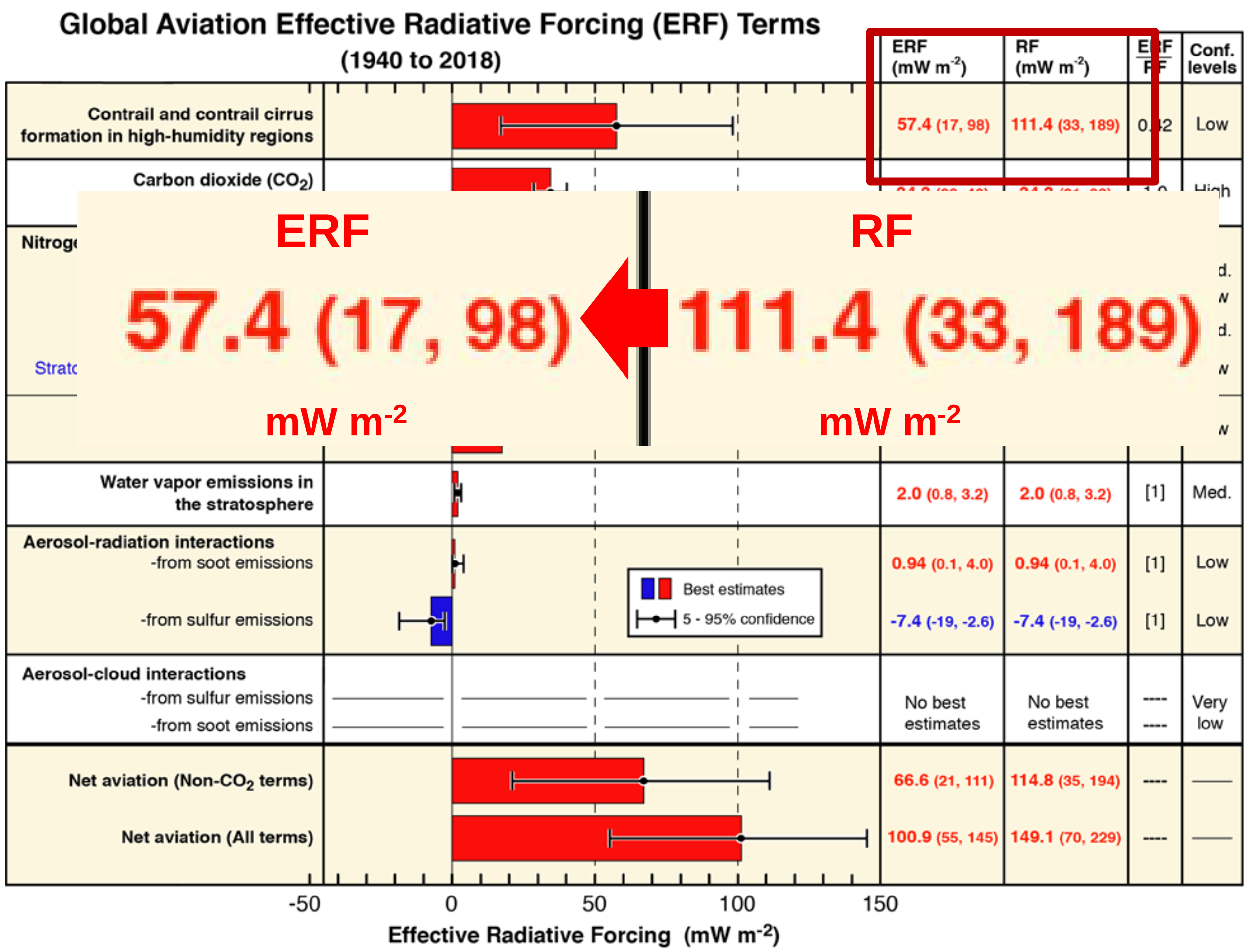
Natural cloud adjustment in response to contrail cirrus formation and development extends over all altitudes, but natural cirrus close to the main flight levels is most strongly affected.

Compensation of aviation induced and natural clouds can be identified over the whole series of simulations, also for smaller aviation scaling.



Global cloud cover change at 250 hPa from ATR-1 to ATR-12

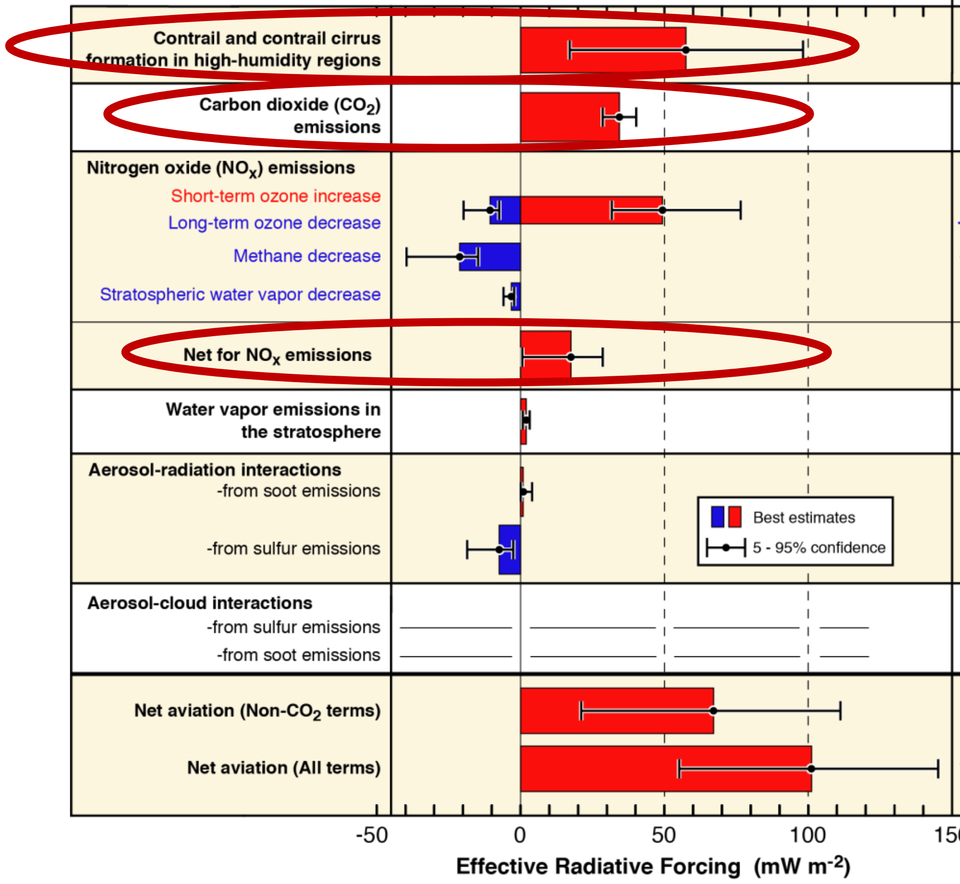
Contrail Cirrus ERF: Still an Important Impact Component



Lee et al.(2020, Atmospheric Environment, Online First)

Contrail Cirrus ERF: Still an Important Impact Component

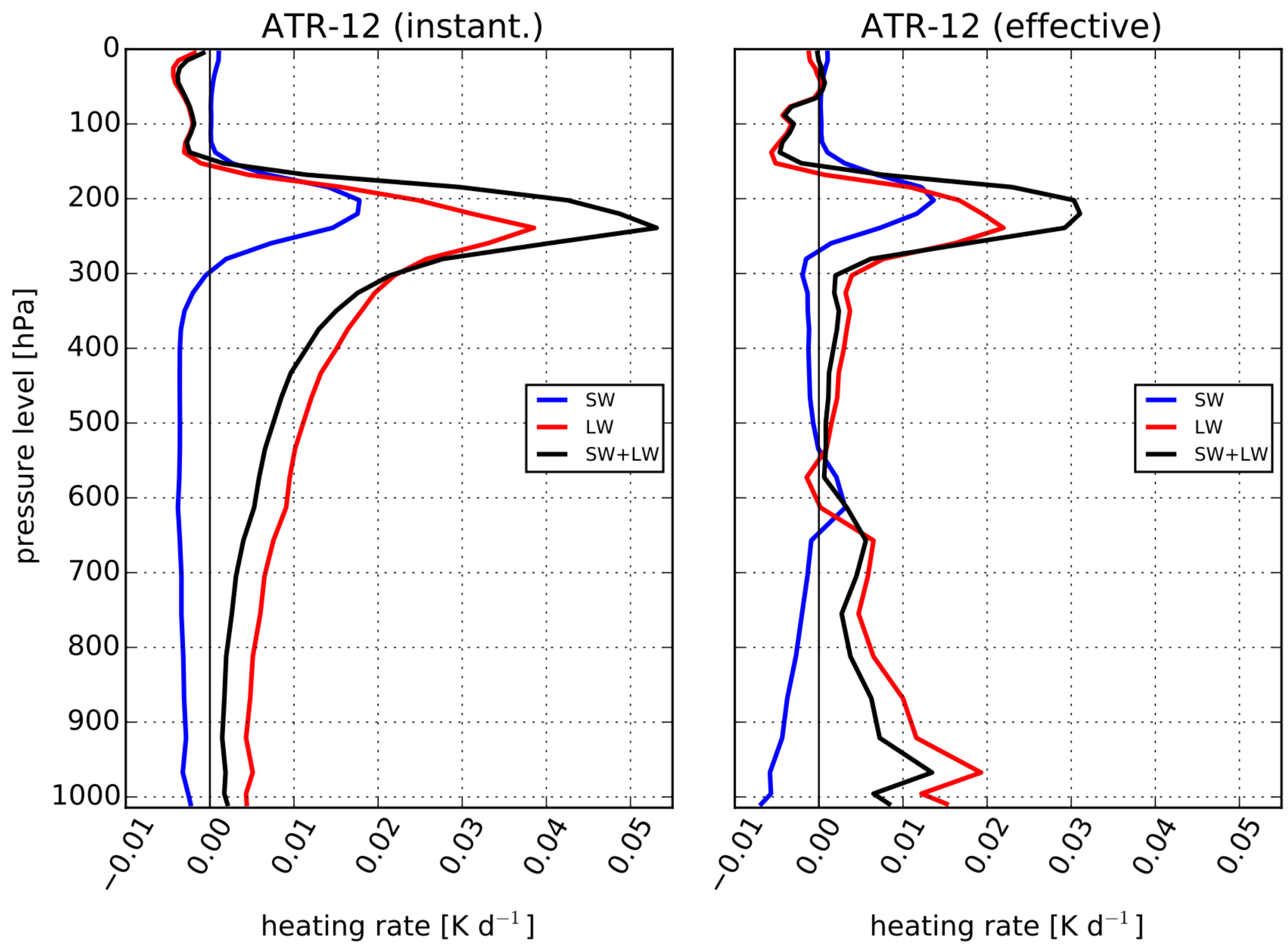
Global Aviation Effective Radiative Forcing (ERF) Terms
(1940 to 2018)



	ERF (mW m⁻²)	RF (mW m⁻²)	ERF/RF	Conf. levels
Contrail and contrail cirrus formation in high-humidity regions	57.4 (17, 98)	111.4 (33, 189)	0.42	Low
Carbon dioxide (CO_2) emissions	34.3 (28, 40)	34.3 (31, 38)	1.0	High
Nitrogen oxide (NO_x) emissions				
Short-term ozone increase	49.3 (32, 76)	36.0 (23, 56)	1.37	Med.
Long-term ozone decrease	-10.6 (-20, -7.4)	-9.0 (-17, -6.3)	1.18	Low
Methane decrease	-21.2 (-40, -15)	-17.9 (-34, -13)	1.18	Med.
Stratospheric water vapor decrease	-3.2 (-6.0, -2.2)	-2.7 (-5.0, -1.9)	1.18	Low
Net for NO_x emissions	17.5 (0.6, 29)	8.2 (-4.8, 16)	----	Low
Water vapor emissions in the stratosphere	2.0 (0.8, 3.2)	2.0 (0.8, 3.2)	[1]	Med.
Aerosol-radiation interactions				
-from soot emissions	0.94 (0.1, 4.0)	0.94 (0.1, 4.0)	[1]	Low
-from sulfur emissions	-7.4 (-19, -2.6)	-7.4 (-19, -2.6)	[1]	Low
Aerosol-cloud interactions	No best estimates	No best estimates		Very low
-from sulfur emissions			----	
-from soot emissions			----	
Net aviation (Non-CO_2 terms)	66.6 (21, 111)	114.8 (35, 194)	----	——
Net aviation (All terms)	100.9 (55, 145)	149.1 (70, 229)	----	——

Lee et al.(2020, Atmospheric Environment, Online First)

Approaching the Determination of Contrail Cirrus Efficacy



Switching from the RF to the ERF framework means that the whole tropospheric heating rate profile induced by contrail cirrus is modified.

The actual heating rate profile will certainly affect the surface temperature response in coupled atmosphere-ocean simulations.

Such simulations are currently underway in order to complete the previous calculations of RFs and ERFs by direct determination of surface temperature change and efficacy.

Conclusions and Outlook

- **ERF of contrail cirrus is substantially reduced with respect to its conventional RF.**
- **The reduction of ERF is much less for a CO_2 forcing.**
- **The main reason for the significant reduction of contrail cirrus ERF is a negative feedback via natural cloud adjustment.**
- **Even if comparing aviation CO_2 forcing and contrail cirrus forcing within the ERF framework, contrail cirrus still makes a large individual contribution to total aviation climate impact.**
- **Whether contrail cirrus efficacy is as small as its ERF/RF ratio suggests remains to be confirmed by forthcoming dedicated climate model simulations (including an interactive ocean).**